

Assessing fisheries carrying capacity in Lake Singkarak, West Sumatera Indonesia to support the endemic bilih fish *Mystacoleucus padangensis* (Bleeker, 1852) species management

¹Setiya Triharyuni, ²Puput F. Rachmawati, ¹Reny Puspasari, ³Puji Rahmadi, ⁴Eko Prianto, ¹Husnah, ¹Sri T. Hartati, ¹Budi Nugraha, ¹Mirna Dwirastina, ^{5,6}Ahmad Fudholi

¹ Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia;

² Bureau of Organization and Human Resources, National Research and Innovation Agency, Jl. M.H. Thamrin No. 8, Central Jakarta 10340 Jakarta, Indonesia; ³ Research Center for Ecology, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno,

Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia; ⁴ Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Universitas Riau, Jl. H.R. Subrantas Km 12.5, Pekanbaru 28293, Riau, Indonesia; ⁵ Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences (LIPI), Jl. Sangkuriang, Bandung, 40135, Indonesia; ⁶ Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia. Corresponding author: S. Triharyuni, setiya.triharyuni@gmail.com

Abstract. Lake Singkarak is the largest lake in the West Sumatra Province, Indonesia. It provides multiple benefits, one of which is in the fisheries sector, where the endemic bilih fish (*Mystacoleucus padangensis*) is a leading domestic product. The bilih fish serves as a source of fishery economic activity. There has been a decline in fisheries production, as evidenced by the overfished exploitation rate, and the diminishing population abundance. The current situation necessitates data and information regarding the carrying capacity of fisheries in Lake Singkarak to assess and develop optimal and sustainable management strategies. This research aimed to investigate the existing conditions of water quality parameters and conduct a carrying capacity assessment for bilih fish as baseline data for bilih fisheries management. This research employed a descriptive exploratory design. Field surveys and laboratory analyses were conducted to identify the biological parameters of the water at six sampling locations. Carrying capacity analysis was utilized to estimate primary productivity following the Beveridge Index, using chlorophyll-a calculations. The average primary productivity was determined to be 274.89 gC/m²/year, and the carrying capacity of fisheries was estimated at 2,398.86 tons of fish/year. Potential fisheries management strategies include the development of community-based fisheries reserves and the regulation of fishing practices through the specification of appropriate catch sizes and environmentally sustainable fishing gear.

Key Words: chlorophyll-a, primary production, water quality.

Introduction. Lake Singkarak is a productive inland water fishery ecosystem in West Sumatra, Indonesia. It serves multiple functions, including tourism, fisheries, power generation, and irrigation. Lakes function as transitory reservoirs within the hydrological cycle, acting as stabilizing elements amidst the dynamic flux of rivers that supply and drain them. This stability facilitates the development and maintenance of diverse habitat structures, establishing intricate planktonic systems. The resulting ecological system supports trophic interactions, with plankton occupying a foundational position in the aquatic food web. Plankton serve as essential primary producers and food sources in

aquatic ecosystems, supporting populations of fish. This crucial role enables the efficient transfer of energy throughout the aquatic food chain (Moss 2015). Lake Singkarak is home to a notable edible endemic herbivorous fish species *Mystacoleucus padangensis* (Bleeker, 1852), commonly referred to as bilih fish, which has played a significant societal role for decades. Bilih fish is characterized by its high nutritional content and economic value, contributing to the welfare of communities surrounding the lake. However, recent observations indicate a decline in the fish population, accompanied by a reduction in the mean length of specimens caught (Syandri et al 2011). The mortality rate due to fishing activity reached 4.86, indicating a strong likelihood of overexploitation. The exploitation rate (E) of 0.54 suggests that fishing activity is at an optimal level; however, it possesses a high potential for overfishing if sustainable fisheries management efforts are not implemented (Amanda et al 2016). Furthermore, this species is listed as Vulnerable under criteria B1 according to International Union for Conservation of Nature (IUCN) (Lumbantobing 2020). This situation has arisen due to several factors, including inadequately managed fishing pressures, the capture of gravid fish, alterations in water quality, significant dependence of fishing communities on this resource, and the absence of established community-based conservation efforts for this fish species (Syandri 2008).

Modern fisheries management primarily focuses on regulating fish exploitation. This encompasses establishing fishing regulations, implementing measures to protect and enhance fish stocks, promoting sustainable fisheries development, and addressing stakeholder conflicts (Hildén 1999). Moreover, additional crucial interventions include regulating fishing practices with respect to closed seasons, designating fishery reserve areas, and implementing fish restocking programs (Syandri et al 2011; Gunarto 2009). This management process involves governmental authorities, local communities, or private rights holders, with the objective of balancing ecological sustainability with economic and social requirements in aquatic ecosystems (Hildén 1999). Fisheries management plays a crucial role in preserving the long-term sustainability of the endemic fish resources of Lake Singkarak. To elucidate the implementation process, various approaches for maintaining fish resources exist, one of which is the valuation of carrying capacity. Carrying capacity is a fundamental concept for ecosystem-based management, which aids in establishing the upper limits of aquaculture production given the environmental constraints and social acceptability of aquaculture (Ross et al 2013). The carrying capacity of water refers to the highest sustainable fish production level achievable within specific aquatic environmental conditions (Siagian 2010). Alternatively, the carrying capacity of natural waters in fisheries represents the upper limit of fish production that can be accommodated by the ecosystem (Legović et al 2008).

Despite the extensive and diverse research conducted on Lake Singkarak, studies specifically addressing its fisheries carrying capacity remain notably absent. This gap represents a critical limitation in understanding the ecological thresholds that regulate fishery exploitation within the lake. The present study aims to fill this gap by developing a quantitative assessment of fisheries carrying capacity, thereby providing essential scientific evidence to support monitoring frameworks and guides in the implementation of sustainable and optimal fisheries management strategies in Lake Singkarak. This research seeks to evaluate the current state of water quality parameters and assess the ecosystem's carrying capacity for *Mystacoleucus padangensis* (bilih fish). The results will provide crucial baseline information for designing and implementing effective management strategies for bilih fisheries, while maintaining resource sustainability and ecological balance.

Material and Method

Description of the study sites. The research was conducted in Lake Singkarak, West Sumatra Province, Indonesia, which is geographically located at 0° 36' 44.17' S – 100° 32' 21.14' E. Primary and secondary data were collected during the field survey in October 2022. Water quality sampling was conducted at six locations (Figure 1) around the Lake. Physical and chemical parameters measured at near-surface level included

temperature, depth, turbidity, pH, conductivity, current, dissolved oxygen (DO), and total dissolved solids (TDS) using a Horiba WQC U-50 (Horiba, Japan) water quality checker.

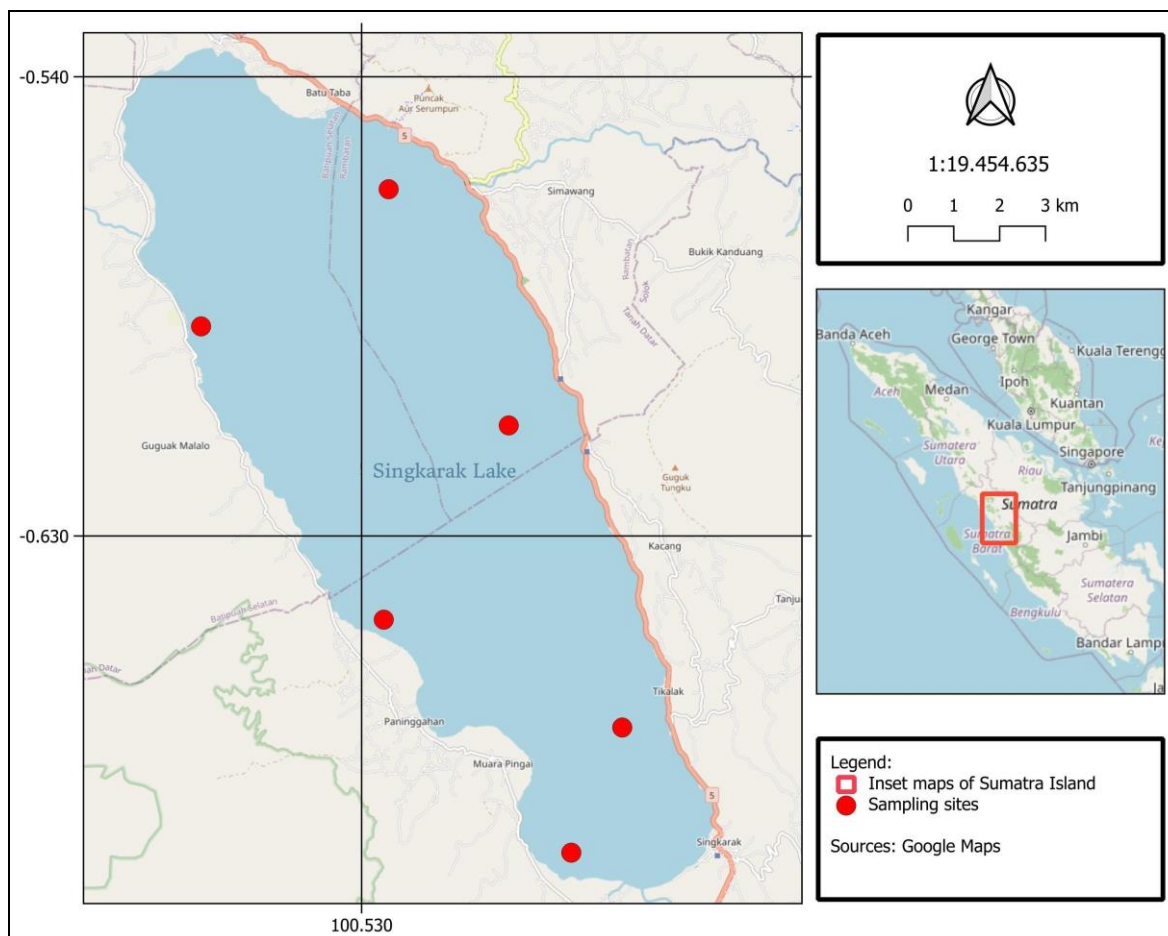


Figure 1. The location of water quality and chlorophyll-a sampling, Lake Singkarak, West Sumatera, Indonesia.

Data collection on fishing gear. Information on fishing gear used to catch bilih fish was obtained through direct field observations and informal semi-structured interviews with local fishers conducted during the sampling period. The respondents were active fishers in the study area, and the interviews aimed to identify and document the fishing gears used for harvesting bilih fish. Based on this approach, three main fishing gears were identified: gill nets, traditional traps locally referred to as alahan, and lift nets equipped with light.

Analysis. The biological parameters assessed were chlorophyll-a concentration and fish diversity. The chlorophyll-a samples were obtained using a vacuum pump from six locations with three repetitions, resulting in a total of six samples. The analyses were conducted according to APHA methods (APHA 1998). To assess the diversity of fish species, all fish captured using a lift net during field observation and landing records were identified in situ based on a fish identification book by Kottelat et al (1993). The total number of fish specimens collected was 297 from four sampling sites.

The lake carrying capacity can be determined utilizing various scientific methodologies, including chlorophyll-a, dissolved oxygen, or total phosphorus calculations. For this study, we employed the determination of the carrying capacity of Lake Singkarak through chlorophyll-a calculation to elucidate the primary productivity in Lake Singkarak. Phytoplankton, a primary producer and natural food source in aquatic environments, contains significant concentrations of chlorophyll-a (Aryawati & Thoha 2011). Primary productivity (ΣPP) is calculated using the maximum chlorophyll-a

concentration (De Silva et al 2006). Chlorophyll-a concentration is utilized to predict primary productivity based on the formula of Smith (2007):

$$\sum PP = \frac{483 * Chla^{1.33}}{9 + 1.15 * Chla^{1.33}}$$

Primary productivity is converted to calculated annual fish production based on conversions presented in Table 1 (Beveridge 1984). Additionally, the estimation of production potential as carrying capacity was estimated using the formula derived from Boyd (1990):

$$Y = 1.43 + 24.48X_c - 0.15X_c^2$$

where Y is fish potential production (kg/ha/year) and X_c is chlorophyll-a concentration (mg/m³).

Table 1

Σ PP conversion of fish production that can be harvested in waters with different primary productivity

<i>PP (gC/m²/year)</i>	<i>Annual fish production (g fish C/m²/year)</i>
< 1000	1.0 - 1.2
1000 - 1500	1.2 - 1.5
2000 - 2500	2.1 - 3.2
2500 - 3000	3.2 - 2.1
3000 - 3500	2.1 - 1.5
3500 - 4000	1.5 - 1.2
4000 - 4500	1.2 - 1.0
> 4500	0.8 - 1.0

Results. Water quality sampling was conducted in the areas proximal to the lake's shoreline, which were assumed as bilih fish (*Mystacoleucus padangensis*) habitat as described by Suryanti et al (2017). The results of water quality observations in October 2022 are presented in Table 2. Sampling locations were situated less than 1 km from the lake shoreline. Variations in parameters among stations were substantial, likely due to water column mixing induced by strong winds, a phenomenon known locally as "banglik water".

The near-surface water temperature ranged from 24.4°C to 28.4°C (mean 27.5°C), aligning with the optimal temperature range from 25°C to 32°C for tropical fish. The pH varied from 6.3 to 8.1 with a mean of 7.6, conducive to bilih fish reproduction and breeding. Turbidity and chlorophyll-a levels were increased at most sites, particularly in places exposed to severe wind-induced mixing. Chlorophyll-a concentration ranged from 2.8 to 11.8 µg/L, classifying Lake Singkarak as eutrophic. This aligns with previous assessments (Susandra et al 2014; Pratiwi et al 2020).

Table 2

Lake Singkarak water quality at the sampling location

<i>Parameter</i>	<i>Stations</i>					
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
Depth (m)	6.9	1.8	0.8	1.1	2.8	4.6
Temperature (°C)	27.8	28.1	28.1	28.4	27.9	24.4
pH	6.3	7.9	8.1	8.1	7.9	7.6
Conductivity	269	166	174	183	190	233
Turbidity	2.7	4.1	3.6	5.0	4.2	2.5
DO (mg/L)	8.7	8.6	7.9	8.5	8.3	2.9
Chlorophyll-a (µg/L)	5.9	4.3	9.5	11.8	11.3	2.8

Fish diversity and catch production. Numerous fish species can maintain populations and growth rates that allow for sustainable harvesting, which is vital for both the ecosystem and fishing-dependent communities. Recent observations identified 6 species of fish and one crustacean, namely bilih fish (*Mystacoleucus padangensis*), belinka (*Puntius belinka*), hampala (*Hampala* sp.), marble goby (*Oxyeleotris marmorata*), pao leiurus (*Tetraodon leiurus*), Nile tilapia (*Oreochromis niloticus*), and freshwater blue claw crayfish (*Cherax quadricarinatus*). The dominant catch was the bilih fish. The limited number of fish species observed was attributed to the prevailing weather conditions during the sampling period, which resulted in decreased fishing activity. The diversity of fish species exhibits a declining trend, as evidenced by previous studies: 19 species reported in 2008 (Syandri 2008), followed by 9 species in 2009 (Herlan et al 2009), and 12 species in 2021 (Safitri et al 2021).

Fishing activities are conducted daily utilizing various types of fishing gear. Interviews with fishers' groups identified three fishing gears employed to catch bilih fish: gill nets, traditional traps locally referred to as alahan, and lift nets with light. The operational time for gill nets is in the morning (05:00 - 07:00), alahan (morning and evening), and lift nets with light (23:00 - 04:30). The mesh size utilized for gill nets ranges from $\frac{5}{8}$ to $\frac{3}{4}$ inches. Concurrently, fishing gear operated with a smaller mesh size may also capture smaller or immature fish. Additional studies indicate that the fishing gear operating in the lake includes gill nets (46.2%), cast nets (49.3%), and fish traps (4.5%) (Batubara et al 2015).

Potential fish production is needed to determine fish stocks in the waters. This study used the chlorophyll-a value approach and primary production conversion to obtain the potential fish production (Boyd 1990). The concentration of chlorophyll-a in water exhibits a positive correlation with productivity (Figure 2). The potential fish production of Lake Singkarak is estimated to reach 176.88 kg/ha/year or 1,929.43 tons/year. To ensure the sustainability of fish resources in Lake Singkarak, the annual catch should be limited to a maximum of 60% of the total potential production. Consequently, the annual catch should not exceed 1157.657 tons/year.

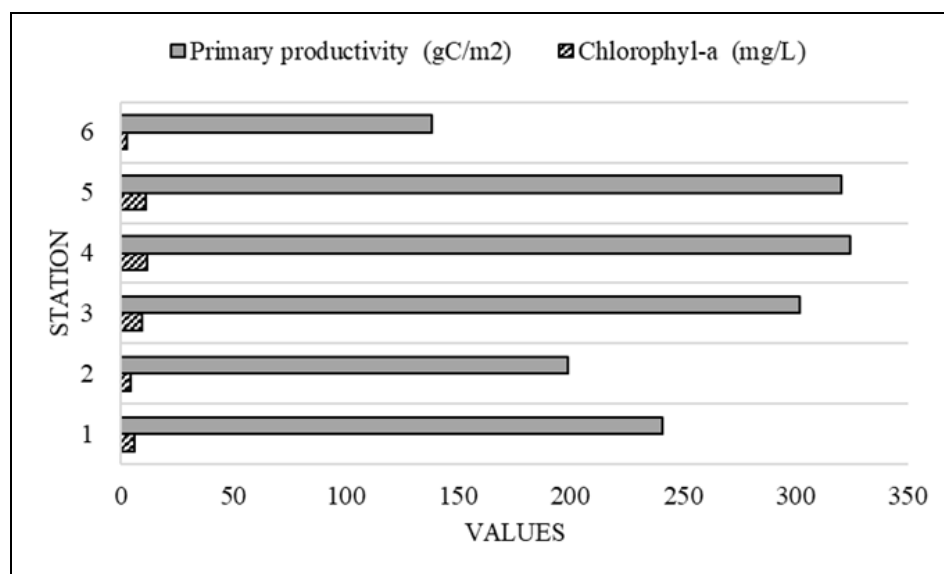


Figure 2. Value of chlorophyll-a and primary productivity in Lake Singkarak (October 2022).

Carrying capacity of fisheries. The carrying capacity was calculated based on primary productivity analysis, which is a function of chlorophyll-a. Chlorophyll-a concentration is used to measure phytoplankton biomass, which is related to primary productivity in aquatic systems. The mean chlorophyll-a concentration was 7.59 $\mu\text{g/l}$, and the primary productivity calculated was 274.89 $\text{gC/m}^2/\text{year}$. The conversion results derived from the efficiency conversion table yielded a value of 0.8%. Given a lake area of approximately 109,082 ha, the production capacity, according to the current carrying capacity, was determined to be 2,398.86 tons/year (Table 3).

Carrying capacity assessment of Lake Singkarak

<i>Parameter</i>	<i>Value</i>	<i>Unit</i>
Primary productivity	274.89	gC/m ² /year
Fish productivity	0.80	%
Fish production	219.91	g fish C/m ² /year
Carrying capacity	2,398.86	tons of fish/year

Discussion. Singkarak Lake's waters provide ideal habitat for bilih (*Mystacoleucus padangensis*) populations. The temperature and pH values are within ideal levels for tropical freshwater fish and support spawning and growth processes. The lake's condition is classified as eutrophic, with a rise in chlorophyll-a levels indicating sufficient nutrient enrichment to maintain primary productivity.

Table 2 shows that near-surface water temperature conditions at all sampling times and locations, except for station 6, were within the same range as the measurements reported by Purnomo et al (2003), which were conducted nearly two decades earlier and indicated that the water temperature remained relatively stable for 20 years. The current study demonstrates that the temperature range tends to be lower compared to the previous study of Syahroma et al (2022). The water temperature range in this study spanned from 24.4°C to 28.38°C, with a mean of 27.5°C. Bilih fish exhibit a preference for temperatures ranging from 26.0°C to 28.0°C (Kartamihardja 2019). Although the water temperature tends to be low, it remains within the optimal temperature range of 25°C - 32°C for tropical fish (Mulyanto 1992).

The pH range observed was 6.3 - 8.1, with a mean value of approximately 7.6. The pH measurements indicate that the water conditions exhibit a tendency towards alkalinity at stations 2, 3, 4, and 5. These four stations are subject to high-velocity winds, which induce water column mixing, thereby influencing the pH values. The mixing condition of the water column resulted in increased water turbidity, as evidenced by elevated turbidity values in stations 2, 3, 4, and 5. The results obtained in May 2022 indicated that the pH of Lake Singkarak ranged from 8.89 to 9.24 (Syahroma et al 2022). The observed average pH value of 7.30 indicates neutral water conditions, which are generally suitable for freshwater fish, including bilih fish, and may support their reproduction and breeding (Nofrita 2017). The optimal pH range for the growth and well-being of most freshwater aquatic organisms is between 6.5 and 9.0 (Novotny & Olem 1994; Zaniboni-Filho et al 2002). The agitated condition of the water column was supported by higher turbidity and chlorophyll-a values observed at four stations. However, chlorophyll-a at station 2 did not follow this pattern. These values were higher compared to the other two stations, namely stations 1 and 6, which exhibited relatively lower turbidity and chlorophyll-a concentrations.

The chlorophyll-a concentration serves as one of the aquatic variables indicatives of trophic status. In Lake Singkarak, the chlorophyll-a concentration ranges from 2.75 to 11.76 µg/L, with a mean value of 7.59 µg/L (Table 2). According to the Trophic State Index (TSI), the chlorophyll-a concentration of Lake Singkarak is classified within the eutrophic category (Pratiwi et al 2020). This index value aligns with the findings of research conducted by Susandra et al (2014), which demonstrates that the chlorophyll-a value ranges from 96.63 µg/L to 103.40 µg/L; consequently, the trophic status of Lake Singkarak waters is categorized as mild eutrophic. Furthermore, Håkanson and Bryhn (2008) delineated the level of water trophic status into four classifications based on chlorophyll-a values. Waters are considered oligotrophic if the chlorophyll-a value is < 2 µg/L, mesotrophic if chlorophyll-a is between 2-6 µg/L, eutrophic if chlorophyll-a is between 6-20 µg/L, and hypertrophic if chlorophyll-a is > 20 µg/L. Based on this classification system, the waters of Lake Singkarak are categorized as eutrophic.

The observed fish ecosystem is dominated by the endemic bilih fish, and species diversity has declined over time. The diversity of fish species exhibits a declining trend, as evidenced by previous studies: 19 species in 2008 (Syandri 2008), followed by 9 species in 2009 (Herlan et al 2009), and 12 species in 2021 (Safitri et al 2021). These

conditions are susceptible to collapse as a result of overfishing or environmental changes. In addition, using of small mesh gear raises the risk of harvesting juveniles and small fish, potentially disrupting recruitment and causing stock depletion in the long term.

Estimating potential production is essential for determining the optimal utilization and management of fish resources for long-term sustainability (Purnomo et al 2013). Chlorophyll-a concentration serves as one method for estimating primary productivity (Sutomo et al 1989). Furthermore, elevated levels of chlorophyll-a and productivity indicate a higher carrying capacity (Riyono et al 2006). The chlorophyll-a data was utilized to calculate the potential value of fish production using the formula presented by Boyd (1990). Based on chlorophyll-a measurements, the potential fish production in Lake Singkarak is estimated at approximately 176.88 kg/ha/year, or 1929.428 tons/year. This value differs significantly from the estimated potential production in 2009, which was only 50.92 kg/ha/year (Herlan et al 2009), and approximately 23.86 kg/ha/year in 2014 (Susandra et al 2014). The disparity in results is attributable to variations in sampling coverage. However, to ensure the sustainability of fish resources, the landing should be adjusted to 60% of total potential production (Kartamihardja 2007). Consequently, the annual catch should not exceed 1,157.657 tons/year. Based on the chlorophyll-a value, the estimated potential for fish production in Lake Singkarak is 4,663 tons/year, and based on the biomass of phytoplankton, the potential for fish production is 21,852 tons/year (Aini et al 2023).

The carrying capacity is defined as the maximum fish abundance that an aquatic ecosystem can sustain over an extended period, influenced by temporal factors, the water body volume, and the amount of waste loaded into the aquatic environment. The fundamental principle of natural fisheries is based on water capacity, including the physical, chemical, and biological conditions. The capacity is related to natural fisheries relying entirely on the natural food chain and do not utilize any chemicals derived from artificial feed sources. Carrying capacity estimates are based on primary productivity and chlorophyll-a concentrations. The correlation between chlorophyll-a and primary productivity is positive. This is as shown in other lakes, such as Lake Maninjau and Lake Cilala in Indonesia (Nurdin et al 2020; Novita et al 2015). These studies confirm that chlorophyll-a concentration is closely correlated with primary productivity, but this relationship may vary depending on a variety parameters like as the inorganic turbidity, the synergistic effect of heavy metals and nutrients, and the monitoring location and depth (von Westernhagen et al 2010). These ecological factors introduce uncertainty into the coefficients utilized for estimating primary productivity from chlorophyll-a concentrations. This uncertainty may result in potential inaccuracies in the prediction of carrying capacity. Additional validation of these coefficients in Lake Singkarak, through direct measurement of photosynthetic rates and nutrient cycling, would enhance the reliability of the carrying capacity estimate. Studies (Beveridge 1996) emphasize the significance of calibrating these models to local conditions to ensure robust management strategies. Based on the results it is shown that the current carrying capacity of Lake Singkarak is 2,398.86 tons/year (Table 3). This finding is comparable to the previous calculation in 2011, which reported 2,245.92 tons/year (Berkademi 2011). However, an alternative study employing the surplus production calculation (Fox model) estimated the environmental carrying capacity at 53,589.44 tons/year (Heri et al 2002). Purnomo et al (2013) asserted that carrying capacity is dependent on the dynamics of water level, surface area, and volume.

Fishing activities exert significant influence on ecosystems, including alterations in the biomass of fish species within the food web, thereby affecting trophic interactions (Pauly et al 2000). The bilih fish (*Mystacoleucus padangensis*) represents the predominant species harvested in Lake Singkarak. Interactions between bilih and other species in the lake influence the ecosystem's carrying capacity from a community ecology perspective. As a pelagic species dependent on zooplankton and phyto-plankton, bilih engages in resource competition with other species occupying the same trophic niche. Moreover, spatial competition may impact resource utilization efficiency and potentially reduce carrying capacity. Ecosystem-based approaches that consider interspecific

relationships and environmental factors are crucial for sustainable management, such as the holistic ecosystem model proposed by Pauly et al (2000).

Fish production exhibited fluctuations from 2013 to 2019 and demonstrated a declining trend. The average catch, particularly for bilih fish, decreased by approximately 6% annually, and the exploitation rate (E) was 0.819 (Herlan et al 2009), indicating an overfishing condition. The mean utilization rate of bilih fish during 2013 - 2018 was 94.53%, which signifies that the exploitation rate was at an overfishing level (Heri et al 2002). Previous research Herlan et al (2009) revealed that fishing mortality exceeded natural mortality. This finding suggests that the reduction of the bilih population in Lake Singkarak is predominantly influenced by fishing activities. Furthermore, the results of the vulnerability study indicate that the vulnerability status of bilih fish is classified as high (Triharyuni et al 2022).

Several management strategies could be implemented to regulate the bilih fishery, including stock enhancement, effort control, and habitat management. Fish stock enhancement is necessary to increase fish production. Stock enhancement can be achieved through the development of culture-based fisheries (CBF) practices, such as stocking, habitat manipulation improvement, and the establishment of fisheries reserves (Welcomme 2011; Lorenzen et al 2000). Moreover, a study by Purnomo et al (2003) indicated that fisheries management efforts in Lake Singkarak were conducted through fishing management initiatives, habitat management via the creation of reservations, and fish population management through restocking/stocking (Syandri et al 2011).

A fish stock enhancement program has been implemented by local universities in collaboration with relevant government institutions. However, it has not elicited a positive response from the local community (Purnomo et al 2006). This condition is attributable to the outcomes of stocking programs that have not achieved their intended objectives, the excessive associated costs, and insufficient community participation (Koeshendrajana et al 2005). Consequently, the development of community-based fisheries reserves and the regulation of fishing practices through the determination of appropriate catch sizes and environmentally sustainable fishing gear are proposed as potential management strategies for the bilih fishery. This alternative management approach aligns with the study conducted by Warsa et al (2020). These management initiatives are anticipated to enhance the economic value and maintain the sustainability of fish resources in Lake Singkarak.

Conclusions. The fisheries carrying capacity of Lake Singkarak is 2,398.86 tons of fish per year. The exploitation rate of bilih fish (*Mystacoleucus padangensis*) has exceeded sustainable levels. Fisheries management is necessary to ensure the sustainability of bilih fish in Lake Singkarak by integrating ecological knowledge with practical management strategies. The development of community-based fisheries reserves and the regulation of fishing through the determination of appropriate catch sizes and environmentally sustainable fishing gear can be considered as options to maintain bilih fish resources. The establishment of community-based reserves involves the engagement of local stakeholders, identification of critical habitats, and implementation of legal and institutional frameworks. Criteria for environmentally sustainable fishing gear should prioritize the minimization of undersized fish catch, reduction of habitat disturbance, and assurance of the long-term sustainability of the bilih population.

Acknowledgements. This paper is part of the research on the analysis of the prey-predator model (trophic interaction) as the foundation for implementing a maximum sustainable yield policy in Lake Singkarak. All authors have made significant contributions and share equal proportions of authorship.

Conflict of interest. The authors declare that there is no conflict of interest.

References

- Aini S., Sudino D., Putra A., Nuraini Y., Maulita M., Ramadhanty N. R., Hamdani H., Aulia D., Suriadin H., 2023 [Estimation of fish production potential in Lake Singkarak West Sumatra based on chlorophyll-a value and abundance of phytoplankton]. *Journal of Indonesian Tropical Fisheries* 6(1):79-85. [in Indonesian]
- Amanda F. F., Ghofur A., Ibrohim I., 2016 [Study of recruitment and exploitation of bilih fish in Lake Singkarak, West Sumatra]. *Proceeding Biology Education Conference* 13(1):701-703. [in Indonesian].
- Aryawati R., Thoha H., 2011 [The relationship between chlorophyll-a content and abundance in the waters of Berau, East Kalimantan]. *Maspari Journal* 02:89-94. [in Indonesian]
- Batubara J., Bukhari, Lasibani S. M., 2015 [Inventory of fishing gear in Lake Singkarak, West Sumatra Province]. *Jurnal Bung Hatta University* 6(2):1-15. [in Indonesian]
- Berkademi W., 2011 [Management of Bilih fish resources (*Mystacoleucus padangensis* Blkr) in Lake Singkarak, West Sumatera]. IPB University. 154 pp. [in Indonesian]
- Beveridge M. C. M., 1996 *Cage aquaculture*. Blackwell Science Ltd. 376 pp.
- Beveridge M. C. M., 1984 *Cage and pen fish farming covering capacity models and environmental impact*. FAO Fish. Tech. Pap. 255. 131 pp.
- Boyd C. E., 1990 *Water quality in ponds for aquaculture*. Alabama Agricultural Experiment Station, Auburn University. 482 pp.
- De Silva S. S., Amarasinghe U. S., Nguyen T. T. T., 2006 *Better-practice approaches for culture-based series development in Asia*. ACIAR Monograph No. 120. 96 pp.
- Gunarto A., 2009 [Conservation of Bilih fish (*Mystacoleucus padangensis*) through the development of fisheries agrotourism in Lake Singkarak, West Sumatra]. *Journal of Environmental Engineering* 5(2):145-156. [in Indonesian]
- Håkanson L., Bryhn A. C., 2008 *Eutrophication in the Baltic Sea: present situation, nutrient transport processes, remedial strategies*. Springer Berlin Heidelberg. 269 pp.
- Heri E. R., Yulinda E., Ari H., 2002 [Bioeconomic analysis of Bilih fish (*Mystacoleucus padangensis*) in Lake Singkarak, West Sumatra Province]. *Coastal Socio-Economic Journal* 3(4):12-22. [in Indonesian]
- Herlan, Samuel, Ditya Y. C., Anggraeni D. P., Dwirastina M., Antoni R., Apriyanti D., Sayani A., 2009 [Estimation of stocks and potential of fish resources in Lake Singkarak and connected rivers, West Sumatra]. Technical Report, Research Institute for Inland Fisheries and Extension. 57 pp. [in Indonesian]
- Hildén M., 1999 *Fisheries management*. In: *Environmental Geology*. Encyclopedia of Earth Science. Springer, Dordrecht. 251-253 pp.
- Kartamihardja E. S., 2019 [Keberhasilan introduksi ikan bilih di Danau Toba perlu pemulihan]. *Warta Iktiologi* 3(1):1-8. [in Indonesian]
- Kartamihardja E. S., 2007 [Plankton biomass size spectra and their potential utilization by fish communities in the limnetic zone of Ir. Djuanda Reservoir, West Java]. Thesis. IPB University. 165 pp. [in Indonesian]
- Koeshendrajana S., Purnomo K., Kartamihardja E. S., 2005 [Problems and alternative solutions for boosting Bilih fish (*Mystacoleucus padangensis*) stocks in Lake Singkarak, West Sumatra (socio-economic and institutional studies)]. *Jurnal Penelitian Perikanan Indonesia*. Edisi Sosial Ekonomi 11(3):51-63. [in Indonesian]
- Kottelat M., Whitten J. A., Kartikasari S. N., Wirjoatmodjo S., 1993 *Freshwater fishes of Western Indonesia and Sulawesi*. Periplus Editions (HK) LTD., Indonesia. 344 pp.
- Legović T., Palerud R., Christensen G., White P., Regpala R., 2008 *A model to estimate aquaculture carrying capacity in three areas of the Philippines*. *J. Science Diliman*, 20(2):31-40.
- Lorenzen K., Amarasinghe U. S., Bartley D. M., Bell J. D., Bilio M., De Silva S. S., Garaway C. J., Hartmann W. D., Kapetsky J. M., Laleye P., Moreau J., Sugunan V. V., Swar D. B., 2000 *Strategic review of enhancements and culture-based fisheries*. Technical Proceedings of the Conference on Aquaculture in the Third Millennium. 221-237 pp.

- Lumbantobing D., 2020 *Mystacoleucus padangensis*. The IUCN Red List of Threatened Species 2020: e.T91059695A91059767. <https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T91059695A91059767.en>
- Moss B., 2015 The dynamics of lakes in relation to fishes and fisheries. In *Freshwater Fisheries Ecology*. Craig, J. F. (Ed). New York: John Wiley & Son, Ltd.. 31-47 pp.
- Mulyanto, 1992 [Living environment for fish]. Departemen Pendidikan dan Kebudayaan. Jakarta. 138 pp. [in Indonesian]
- Nofrita, 2017 [Ecomorphology and reproductive characteristics of bilih fish (*Mystacoleucus padangensis* Bleeker, Pisces: Cyprinidae) in river and lake habitats]. Doctoral dissertation, Universitas Andalas, Indonesia. 99 pp. [in Indonesian]
- Novita M. Z., Soewardi K., Pratiwi N. K. M., 2015 [Aquatic carrying capacity assessment for extensive fishing (Case Study: Cilala Lake, Bogor Regency)]. *Jurnal Ilmu Pertanian Indonesia (JIPI)* 20(1):66-71. [in Indonesian]
- Novotny V., Olem H., 1994 *Water quality: prevention, identification and management of diffuse pollution*. Van Nostrand Reinhold. New-York. 1072 pp.
- Nurdin J., Irawan D., Syandri H., Nofrita, Rizaldi, 2020 Phytoplankton and the correlation to primary productivity, chlorophyll-a, and nutrients in Lake Maninjau, West Sumatra, Indonesia. *AAFL Bioflux* 13(3):1689-1702.
- Pauly D., Christensen V., Walters C., 2000 Ecopath, Ecosim and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* 57:697-706.
- Pratiwi T. M. N, Hariyadi S., Soegesty N. B., Wulandari D. Y., 2020 [Determination of trophic status through several approaches (case study: Cirata Reservoir)]. *Jurnal Biologi Indonesia* 16(1):89-98. [in Indonesian]
- Purnomo K., Andri W., Kartamihardha E. S., 2013 [Carrying capacity and potential fish yield of Sempor Reservoir at Kebumen Regency-Central Java province]. *Jurnal Lit. Perikanan Ind.* 19(4):203-212. [in Indonesian]
- Purnomo K., Kartamihardja E. S., Koeshendrajana S., 2006 [Efforts to boost Bilih fish (*Mystacoleucus padangensis*) stock in Lake Singkarak]. *Prosiding Seminar Nasional Ikan IV*:11-18. [in Indonesian]
- Purnomo K., Kartamihardja E. S., Koeshendrajana S., 2003 [Growth, mortality, and feeding habits of introduced Siamese catfish (*Pangasius hypopthalmus*) in Wonogiri Reservoir]. *Journal of Indonesian Fisheries Research* 9(3):13-20. [in Indonesian]
- Riyono S. H., Afdal, Rozak A., 2006 [Condition of Klabat Bay waters reviewed from the chlorophyll-a content of phytoplankton]. *Oseanologi dan Limnologi di Indonesia* 39:19-36. [in Indonesian]
- Ross L. G., Telfer T. C., Falconer L., Soto D., Aguilar-Manjarrez J., Asmah R., Bermúdez J., Beveridge M. C. M., Byron C. J., Clément A., Corner R., Costa-Pierce B. A., Cross S., De Wit M., Dong S., Ferreira J. G., Kapetsky J. M., Karakassis I., Leschen W., Little D., Lundebye A.-K., Murray F. J., Phillips M., Ramos L., Sadek S., Scott P. C., Valle-levinson A., Waley D., White P. G., Zhu C., 2013 Carrying capacities and site selection within the ecosystem approach to aquaculture. In L. G. Ross, T. C. Telfer, L. Falconer, D. Soto & J. Aguilar-Manjarrez, eds. *Site selection and carrying capacities for inland and coastal aquaculture*. 19-46 pp. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6-8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome FAO. 282 pp.
- Safitri R., Wahidi I., Safitri E., 2021 [Fish species found in Lake Singkarak, West Sumatra]. *Proceedings of the National Seminar on Biology Education*. 303-310 pp. [in Indonesian]
- Siagian M., 2010 [The carrying capacity of the Koto Panjang Kampar Hydroelectric Power Plant Reservoir, Riau Province]. *Jurnal Perikanan dan Kelautan* 15(1):25-38. [in Indonesian]
- Smith V. H., 2007 Using primary productivity as an index of coastal eutrophication: The units of measurement matter. *Journal of Plankton Research* 29(1):1-6.

- Suryanti A., Sulistiono, Muchsin I., Kartamihardja E. S., 2017 [Spawning and nursery ground of bilih fish *Mystacoleucus padangensis* (Bleeker, 1852) in the Naborsahan River, Lake Toba, North Sumatera]. BAWAL 9(1):33-42. [in Indonesian]
- Susandra R. E., Syandri H., Elfrida, 2014 [Tropical status and estimation of fish production potential in the littoral waters of Lake Singkarak, West Sumatra]. Jurnal Universitas Bung Hatta 4(1):1-13. [in Indonesian]
- Sutomo, Riyono S. H., Santoso, 1989 [Phytoplankton chlorophyll content in Ujung Watu, Jepara, Central Java]. In D. P. Praseno, W. S. Atmadja, O. H. Arinardi, Ruyitno, & I. Supangat (Eds.), Oceanological research in Indonesian waters, Book I: Biology, geology, environment, and oceanography. 76–80 pp. [in Indonesian]
- Syahroma H. N., Syawal M. S., Akhdiana I., 2022 Distribution and habitat characteristics of endemic Bilih fish (*Mystacoleucus padangensis* Blkr) in Lake Singkarak, West Sumatra. IOP Conf. Series: Earth and Environmental Science 1036(1):012120. <https://doi.org/10.1088/1755-1315/1036/1/012120>
- Syandri H., Junaidi, Azrita, 2011 [Management of endemic Bilih fish resources (*Mystacoleucus padangensis* Blkr) based on local wisdom in Lake Singkarak]. J. Kebijak. Perikan. Ind. 3(2):135-144. [in Indonesian].
- Syandri H., 2008 [Threats to the germplasm of bilih fish (*Mystacoleucus padangensis* Blkr) and its conservation efforts in Lake Singkarak]. Scientific inaugural lecture for the appointment of a full professor at the Faculty of Fisheries and Marine Sciences, Bung Hatta University, Padang. 25 pp. [in Indonesian]
- Triharyuni S., Rahmadi P., Puspasari R., Rachmawati P.F., Prianto E., 2022 Vulnerability of endemic Bilih fish (*Mystacoleucus padangensis*) Bleeker, 1852 in Lake Singkarak, West Sumatera, Indonesia. IOP Conf. Series: Earth and Environmental Science 1119:012010. <https://doi.org/10.1088/1755-1315/1119/1/012010>
- Warsa A., Tjajo D. W. H., Astuti L. P., 2020 [Conservation efforts for bilih fish (*Mystacoleucus padangensis*) by determining catch size and sanctuary in Lake Singkarak]. Jurnal Airaha IX(1):36-48. [in Indonesian].
- Welcomme R., 2011 Review of the state of the world fishery resources: inland fisheries. FAO Fisheries and Aquaculture Circular. 97 pp.
- von Westernhagen N., Hamilton D. P., Pilditch C. A., 2010 Temporal and spatial variations in phytoplankton productivity in surface waters of a warm-temperate, monomictic lake in New Zealand. Hydrobiologia 652(1):57–70.
- Zaniboni-Filho E., Meurer S., Golombieski J. I., Silva L. V., Baldisserotto B., 2002 Survival of *Prochilodus linetaus* (Valenciennes) fingerlings exposed to acute pH changes. Acta Scientiarum 24(4):917-920.
- *** American Public Health Association (APHA), 1998 Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association, Washington, DC, USA. 2671 pp.

Received: 27 June 2025. Accepted: 11 December 2025. Published online: 18 May 2026.

Authors:

Setiya Triharyuni, Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: setiya.triharyuni@gmail.com

Puput F. Rachmawati, Bureau of Organization and Human Resources, National Research and Innovation Agency, Jl. M.H. Thamrin No. 8, Central Jakarta 10340 Jakarta, Indonesia, e-mail: puputfr@gmail.com

Reny Puspasari, Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: reny.paksi@gmail.com

Puji Rahmadi, Research Center for Ecology, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: puji.rahmadi@gmail.com

Eko Prianto, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Universitas Riau, Jl. H.R. Subrantas Km 12.5, Pekanbaru 28293, Riau, Indonesia, e-mail: ekobpppu@gmail.com

Husnah, Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: husnahsamhudi@gmail.com

Sri T. Hartati, Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: sriturni@yahoo.com

Budi Nugraha, Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: budinug73@gmail.com

Mirna Dwirastina, Research Center for Biota System, Research Organization for Life Science and Environment, National Research and Innovation Agency, Kawasan Sains Teknologi Dr. (H.C) Ir. H. Soekarno, Jl. Raya Bogor KM. 46, Cibinong, 16911, West Java, Indonesia, e-mail: mirna.rastina@gmail.com

Ahmad Fudholi, Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences (LIPI), Jl. Sangkuriang, Bandung, 40135, Indonesia, email: a.fudholi@gmail.com

This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

How to cite this article:

Triharyuni S., Rachmawati P. F., Puspasari R., Rahmadi P., Prianto E., Husnah, Hartati S. T., Nugraha B., Dwirastina M., Fudholi A., 2026 Assessing fisheries carrying capacity in Lake Singkarak, West Sumatera Indonesia to support the endemic bilih fish *Mystacoleucus padangensis* (Bleeker, 1852) species management. *AAFL Bioflux* 19(3):1016-1027.